Chapter 5

Overall Raw Material Prospecting

Overall Raw Materials Investigations

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Overall investigations of raw materials

1. INTRODUCTION

The overall raw materials exploration serves the purpose of acquiring sufficient data on a raw material deposit in order to establish a **feasibility study** for a project. It is important that the investigation program is well specified and that the responsibilities are clearly defined. This incorporates methods, responsibilities, information flow, cost controls, schedule and milestones.

The investigations of the quality and the quantity of 1 to 3 deposits (which were shortlisted in the preliminary field investigations) are appraised. The following work needs to be carried out in order to obtain accurate information about the deposits:

- Geological mapping and cross-sections.
  - Purpose : Distribution of the lithology / formations and geological structure
- Drilling :
  - 1'000 to 2'000 m of core drilling for the main limestone deposit
  - 500 to 1'000 m for the secondary deposits.
  - Purpose : Description of the lithology, sedimentology, structure, moisture content, porosity, density, compressive strength, sampling for chemical analyses
- Chemical analyses :
  - LOI, SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, SO_3, K_2O,Na_2O,TiO_2, P_2O_5, Mn_2O_3, Cl^-
- Calculation of reserves
- Geophysics if necessary
- Raw mix design
- Preliminary concept of quarrying
- Bulk samples for technological tests

The results of these investigations must be sufficiently precise in order to decide on the feasibility of the project with regard to the raw material aspects.

2. DRILLING

During the overall exploration program, the deposit is investigated by drilling. In order to obtain the most reliable knowledge with respect to the chemical composition and the structure of the rocks, a comprehensive drilling programme is established. In this step, the drilling tool is generally a diamond core drill. This is the finest manner in which the lithology can be precisely described (defined), geological structures can be measured on the cores, and the core recovery of a drill hole can be accurately measured. It is very important to have a maximum core recovery, as the accuracy of the chemical character and the reserves determination of the deposit depends on core recovered.

2.1 Diamond core drill

These involve driving a fast rotating annular bit through the rock and so obtaining a solid undisturbed sample. The bits are either diamond impregnated or surface set. Occasionally other materials such as tungsten may be used. In terms of sample weight or lineal metreage this is at least three times as expensive as any other drilling methods for similar depths.

The drilling equipment is mounted on a frame or on a truck. This includes the drill, mast and water/air circulation pump. This frame may be mounted on skids to be towed or fitted with jack-legs (hydraulic rams), Alternatively it can be mounted on a truck or crawler track device as a permanent configuration.

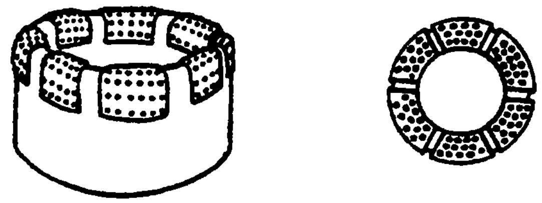
2.1.1 Bits

The bits consist of a steel blank, to the lower end of which a metallic alloy matrix is sintered. This matrix is encrusted or impregnated with diamond grains (natural or synthetic) or occasionally with chips of tungsten carbide or silicon carbide as special alternative.

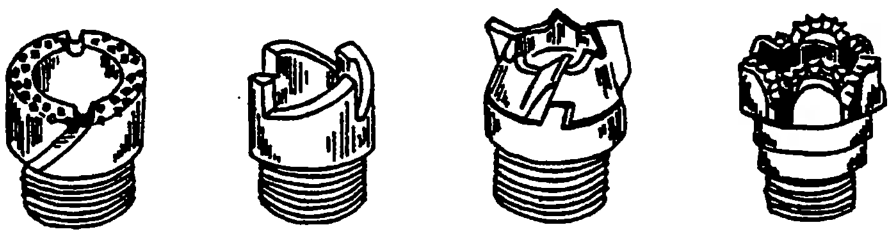
In soft formations such as clay, larger teeth or blades are needed. The cutting edge being made of tungsten or silicon carbide or polycrystalline diamond.

Fig. 1: Types of bits

Hard formations



Soft formations



2.1.2 Circulating fluids

The principal purpose of a circulating fluid is to remove the cuttings from the face of the bit as well as serve as a coolant to the bit. Water or an emulsion of water and special lubricants (barite, polymer oil) also known as drilling mud,is the common circulating fluid. The cuttings are washed up the borehole in the annular space between the drilling rods and the borehole wall or casing. Some drilling techniques (rotary and percussion) use air as the flushing medium. In special circumstances, air can be used to avoid dissolving minerals and losing the core, such as halite (NaCl) in the circulating water.

2.1.3 Core barrel

Core is collected at the bottom of the borehole in a core barrel and periodically. brought to the surface A conventional standard core barrel requires all the drilling rods to be removed from the borehole at the end of each run, before the core can be removed. In 1961, the wireline drilling system was introduced. This enables an innertube with the core (inner core barrel) to be withdrawn through the rods at the end of a cable or wire. This system obviates the need to withdraw all the drilling rods thereby saving time and money. Additionally the quality of the core and core recovery is improved when using wireline drilling.

A core barrel is that section of the drilling rods string in which the cylinder of rock is collected and can be brought to the surface. The simplest core barrel (single tube) consists of a reamer, a corelifter and the core barrel. The reamer serves two functions. One being to maintain the correct hole diameter to ensure sufficient clearance between the borehole wall and drilling rods, and the other, to provide seating for the corelifter. The corelifter consists of a tapered spring-steel ring, which allows the core to travel in one direction only (upwards). When the rods are lifted, the core is wedged in and clamps inside the core barrel.

The corelifter not only prevents the cut core from dropping out, but also allows the core to be broken off at the bottom of the hole. The circulating fluid passes down through the center of the drilling rods past the collected core (in the core barrel) and out over the bit before returning to the surface on the ouside of the drilling rods.

In the double tube barrel, the drilling fluid is diverted away from the core to the bit by way of the annulus between the core barrel and the innertube. This system was devised for soft, broken or friable ground, where the core could be easily washed away by the driling fluid. In subsequent models, the innertube is fixed with a ballrace so that it cannot rotate with the rods thereby cause grinding and wearing of core. A further refinement is a split innertube to allow better transfer of undisturbed core into the trays.

In very soft, unconsolidated or porous rocks it is necessary to use a triple tube core barrel with split innertube to obtain a good recovery.

2.1.4 Recovery

The drilling should be carried out in such a manner that a maximum core recovery is ensured.

The minimum core recovery is 95% per drill hole. Below 80 %, the accuracy of the geological information derived and associated chemical analysis is doubtful.

According to Holderbank drilling specifications, the client has the right to reject the core and therefore the samples received from the drilling contractor if the core recovery is below 80%. Only if the insufficient core recovery is due to inadequate drilling. In which event, the contractor is obliged to redrill the borehole at no cost to the client. On the other hand the drilling contractor, cannot be held responsible if the geologist confirms that the poor core recovery is due to lithological features (e.g. cavities, caves, incompetent ground, etc).

Good core recovery is difficult to obtain from unconsolidated material for two reasons:

- large gravel pieces tend to either move about in the core bit and so prevent clean cutting or they jam in the bit
- fine sand, whilst feeding into the barrel, will not be rigid enough to be retained by the core lifter.

2.1.5 Core size

Core size depends on the bit and barrel combination used. In general for our purposes, the core size will have a minimum diameter of 45 mm (or NQ-3). In broken material, recovery will be better with a larger core size. In very hard material, recovery is invariably very good, at lower cost when using the smallest core which will be suitable for our purposes.

2.1.6 Core storage

The cores must be stored in wooden core boxes or trays, which are lockable. The core boxes must be adequately marked on the outside showing borehole co-ordinates (number), box number, depth of drilling (from... to) in meters. Generally, the inside length of the core box is 1.05m. whilst the width of the inside sections (usually 5 sections) should be +/- 5 mm larger than the core diameter. The inside of the core box must likewise, be adequately marked showing top and bottom depth of each section with an arrow pointing down hole. Every run of the core barrel must be 'flagged' using tags, labels or wooden blocks. Information on the flags indicates run number and depth. Pieces of wood of appropriate length must be inserted into the core boxes to indicate voids or cavities, as they are encountered in the actual borehole. The core boxes or trays, must be stored in suitable coe shed which is protected against atmospheric conditions, vandalism and competitor interference.

2.1.7 Core sampling and preparation

The project geologist is responsible for samples selection of the cores according to acceptable geological practice. The sample widths are to be adequately marked on the cores and recorded in the borehole log.

Samples preparation procedure is important so that representative samples are supplied to the laboratory for analysis. The borehole cores are split (or divided) length-wise (from top to bottom) into two halves using a stone saw or a core splitter installed on site. One half is returned to the respective core box, and is adequately stored as the geological reference.

The other half is crushed and comminuted, sample for sample, according to the geologically defined intervals, to a grain size of max. 2 mm. The original sample of several kilograms is in a series of several steps of alternate crushing and quartering reduced to a final mass of about 200 grams.

The intermediate fractions not used for further processing will have to be adequately stored in labeled plastic bags.

The +/- 200 grams final sample material is ground with a laboratory mill to 0% residue on a 60 micron sieve (10'000 mesh per cm^2).

For both client and "Holderbank" one sample of approx. 50 g each should be prepared for chemical analysis.

2.1.8 Drilling problems

The main problems encountered during a drilling campaign are as follows:

Access

Sometimes, the access to the drillpoint is very difficult. Access roads have to be built or the drilling equipment will have to be dismantled and carried.

Recovery

A good recovery depends on the experience of the man in charge of the drilling. In case of poor or soft rock, which leads to bad recovery, a double or triple tube core barrel is recommended.

Others problems consist of loss of water, deviation of the drill holes, stabilility of the hole/casing, etc...

2.2 Other types of drilling

2.2.1 Auger drill

The principal component is a slowly rotating rod. The material from the hole is forced upwards by the wedging action of the cutting bit tips and by a spiral flue (archimides screw) fitted to the rods.

These rigs are mainly used for post hole digging and sampling of soil, clay and shallow weathered rock, in situations where disturbed samples are acceptable. These rigs are unsuitable in unconsolidated alluvial (pebble, sand, clay) or hard rocks.

2.2.2 Rotary drill

This method uses a slowly rotating rod string at the end of which a bit scrapes and dislodges rock chips by point pressure. The cuttings are flushed usually flushed by air although water or drilling mud (emulsion of barite and water) is used in special circumstances. Circulation may be normal, i.e. cuttings are exhausted from the borehole between the rod and the borehole hole wall or casing, or may be reversed (RC), whereby cuttings are exhausted through the interior of the rods.

Reversed circulating drilling may be used for geochemical sampling. The price of the RC drilling is much cheaper than the core drilling, but geophysical logging must be carried out to for correlation between the drill holes. The total costs (RC drilling plus geophysics) are still good, compared to those of core drilling (30 to 60% lower).

Rotary drilling methods are frequently applied in oil well drilling.

2.2.3 Percussion drill

As the term suggests the principle thereof is having a slowly rotating chisel impacting the rock. The method of application of force to the chisel allows a classification as follows:

- uphole hammer drill
- downhole hammer drill.

Normally applied in production drilling (blasthole) in open pit or quarry operations.

3. GEOLOGICAL MAPS AND CROSS -SECTIONS

3.1 Geological mapping

A geological map is a representation of the surface outcrop rocks, very often superimposed on on a topographical map. Geological mapping is therefore essential to study the spatial distribution of the different rock types, to determine their thickness and to investigate the geological structure of the deposit. Many folds or faults, for instance, can be discovered or confirmed (from areial photography) by geological mapping. If seen in outcrop, these features must be mapped over a large area to be understood. Geologic maps are the basis on which one can construct the cross sections. The shape and structure of the deposit is therefore better understood through detailed geological mapping.

The scale of a detailed geological / topographic map is generally 1 : 1000 to 1 : 2000 with a contour line of 1 m.

Each formation encountered in the field is characterised by a specific colour or symbol on the map and their relative age is indicated in a legend. The legend customarily has a specific sequence. The oldest rock formation is listed at the bottom followed by the others in order of their decreasing age, ending with the youngest formation at the top of the legend (Fig. 2)

The geologist must characterise each exposure or layer and attribute them to a formation. The fossil content, sedimentary structures and their lithological aspects allow one to characterise them.

Moreover, the geological map shows the structures of the deposit (Fig 3). The dip and the strike of the layers, as well as the faults and the folds are drawn on the map. Fig. 4 shows the conventional symbols.

Fig. 2: **Statigraphical column with the thickness of the formations**

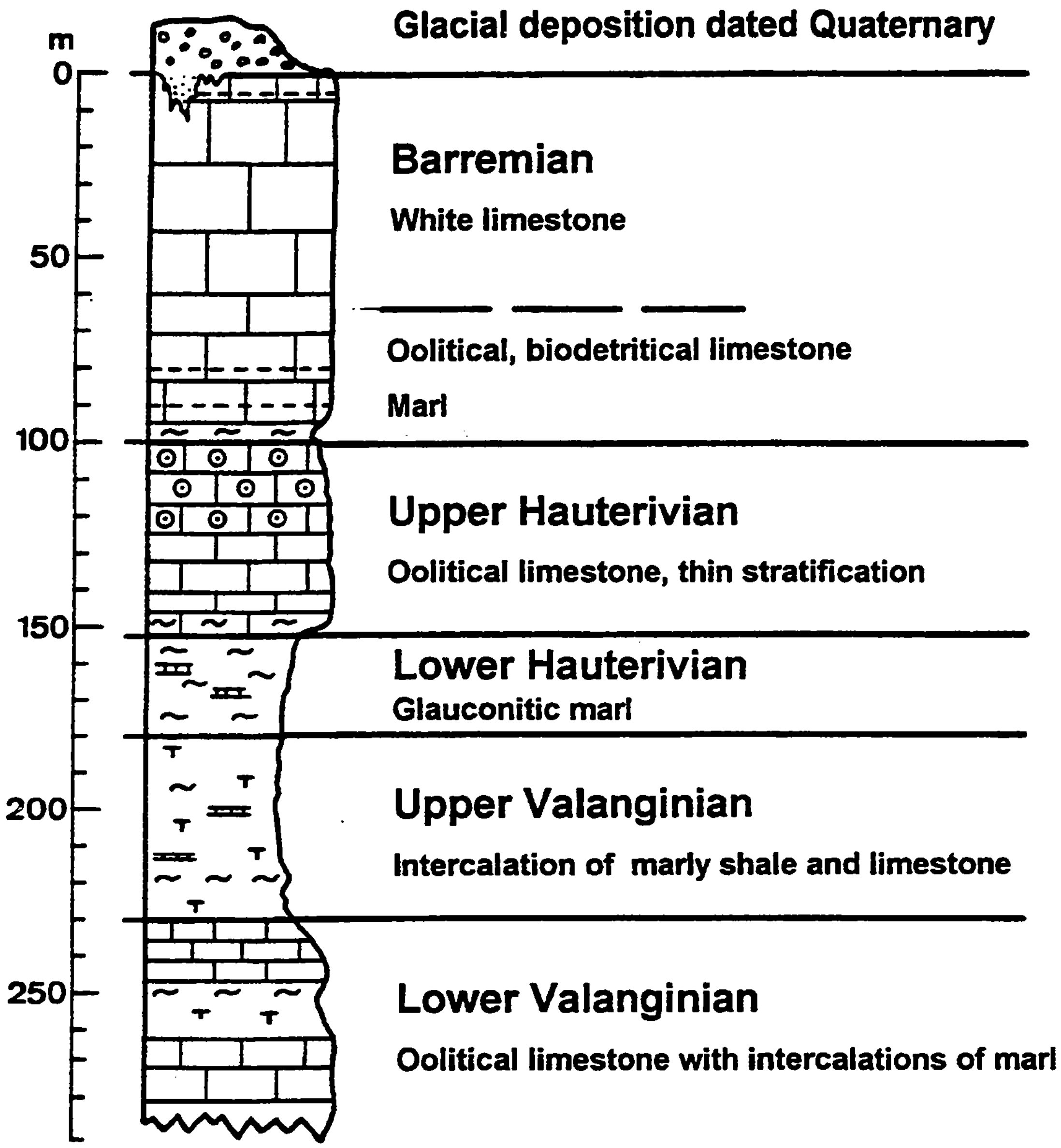


Fig. 3: Geological map, scale 1: 2000

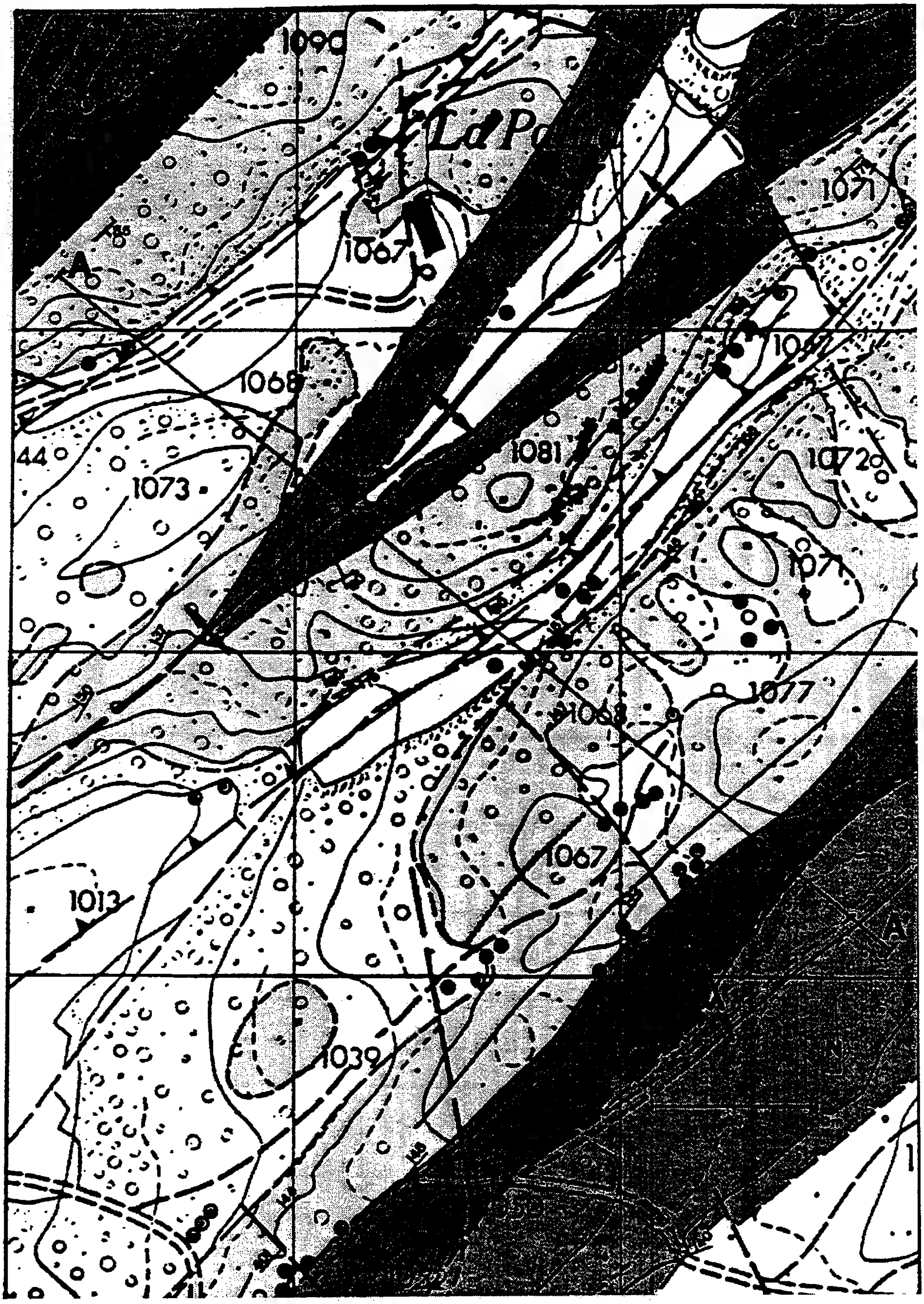
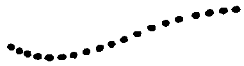
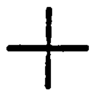
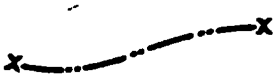
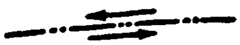


Fig. 4: Mapping symbols

Contacts of one formation to another		contact
		contact showing dip
		contact approximate position
		indefinite contact
		contact concealed
Bedding		bedding, strike and dip
		horizontal bedding
		vertical bedding
Faults (in red normally to distinguish from contacts)		fault
		fault approximate
		relative lateral movement
		thrust
Folds		trace of axial plane and plunge of axis

Considering the discontinuity of the exposures due to the vegetation, overburden, alluvial deposits, etc. geological mapping is not easy and depends on the experience of the geologist. The geologist must use the knowledge available with regard to stratigraphy and tectonism of the region, in order to create a geological 'model'. This 'model' will be continuously compared with the field observations to get a more realistic image. This method of fieldwork allows one to obtain reliable knowledge very rapidly over a large area in spite of discontinuous exposures.

3.2 Geological cross-sections

Geological cross-sections show a section in a vertical plan (Fig. 5). They show a postulated distribution of the rocks at depth. Based on the geological situation observed at the surface (geological map) as well as information derived from drilling and geophysical surveys.

The geologist's structural interpretation can supported by the results of the drilling campaign. Correlation of the geological map and the results of the drillings give a reliable image of the sub-surface geological conditions. Refer Fig 6.

The significance of the geological interpretation of the deposit structures for the calculation of reserves is illustrated in Fig. 7.

Although the height of the outcrops of limestone is almost identical, the exploitable quantities are significantly different. Horizontally layered deposits (Fig. 7a) contain considerably larger quantities of exploitable materials than a deposit of inclined stratification. This is obvious for cases of where the strata dip outwards (Fig. 7b). Equally important also important in the opposite situation where the starta dip inwards(Fig 7c), because of increasing quantities of overburden to be removed.

Fig. 5: Geological cross-section, scale 1 : 2000

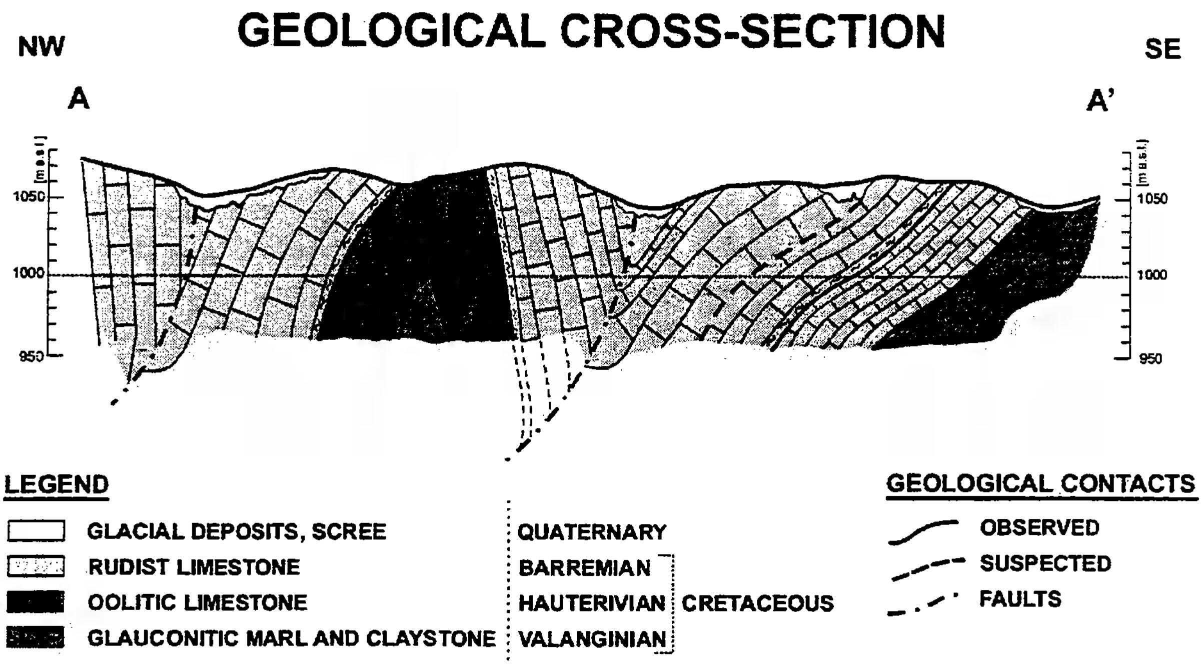


Fig. 6: **Correlation between cross-section and drill hole data**

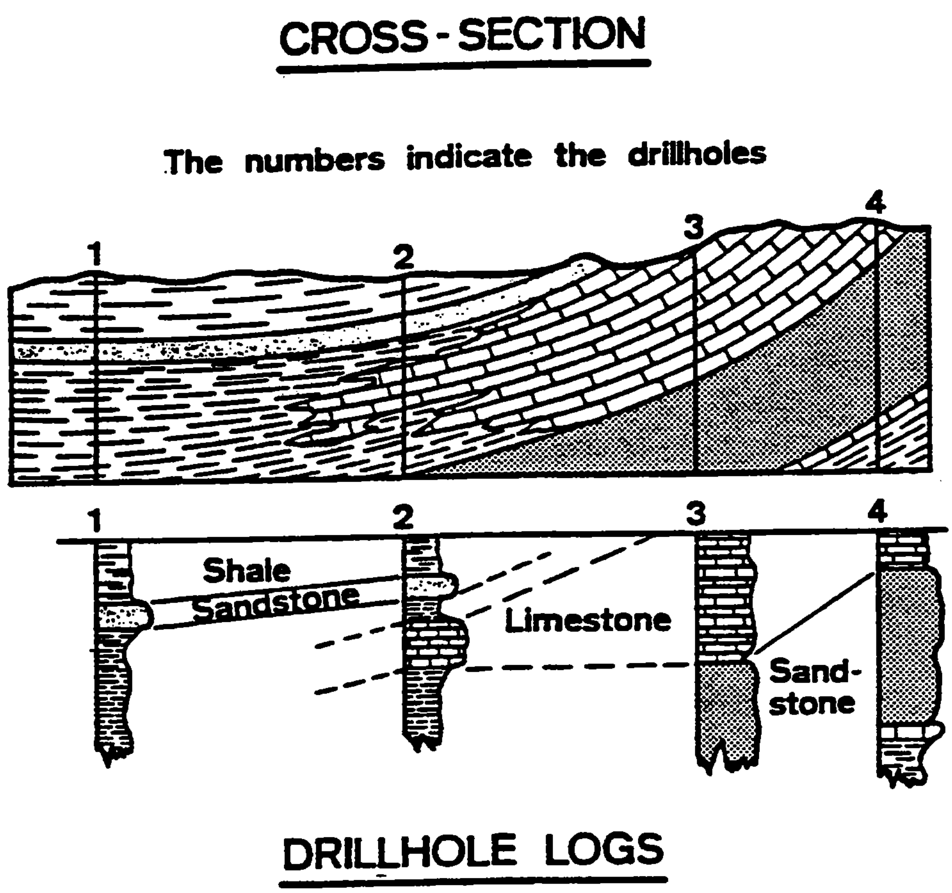
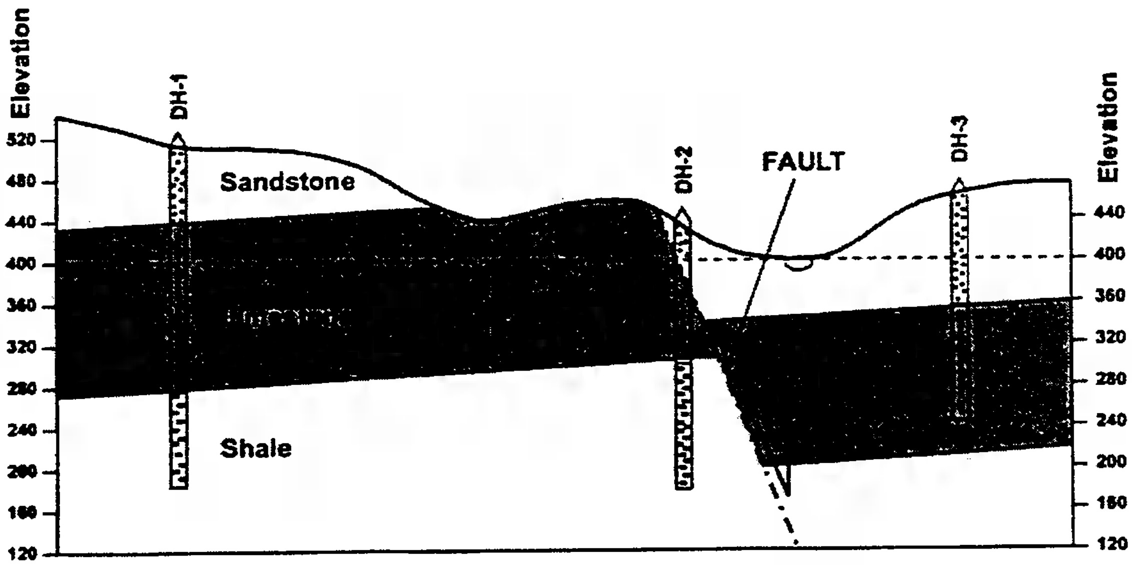
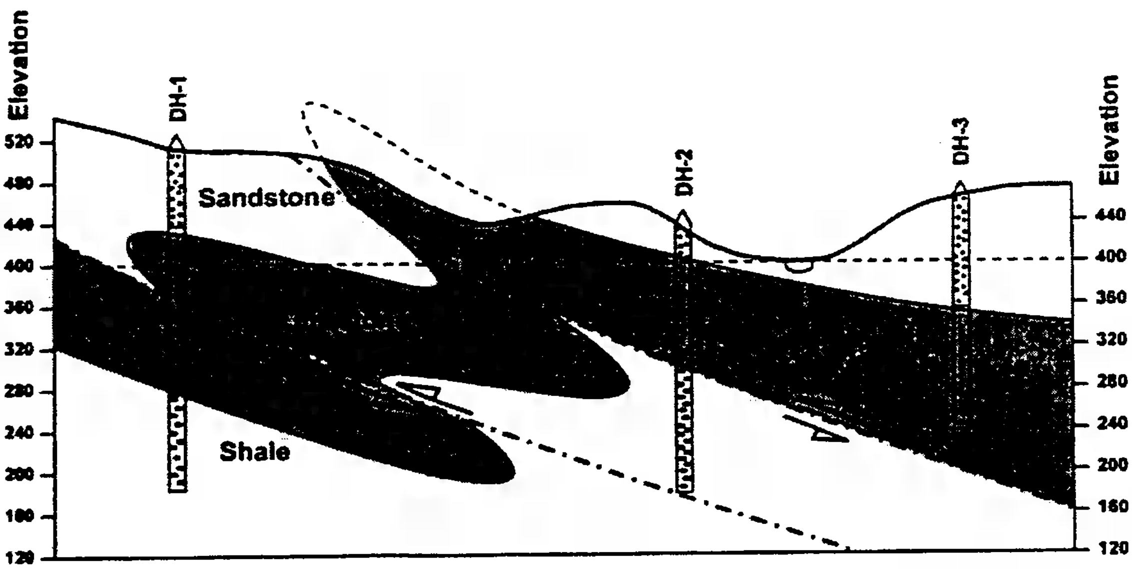


Fig. 6a Limestone Correlation - Alternative Solutions



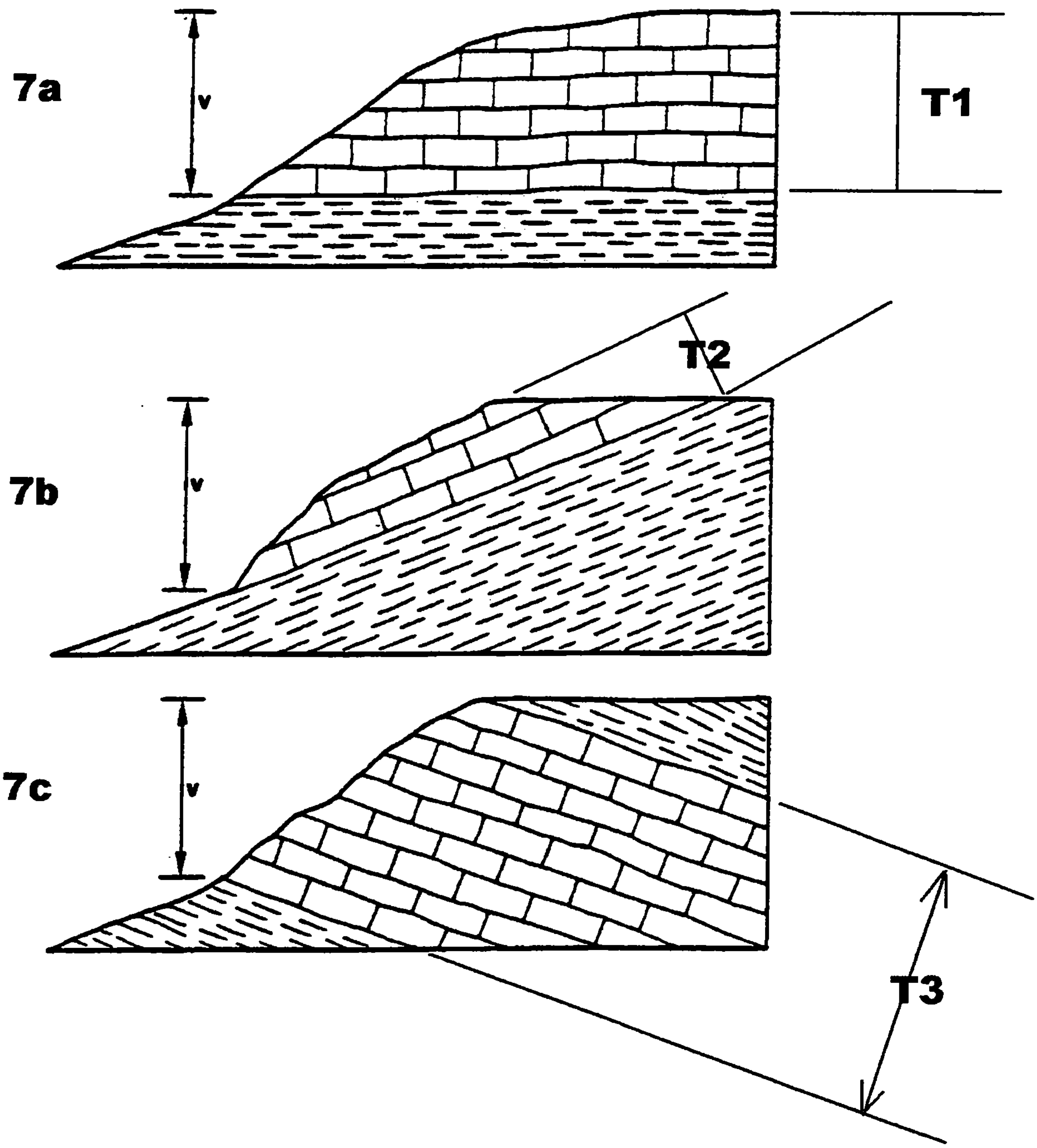
NORMAL FAULTING



THRUSTED LIMESTONE

Another aspect to consider is the intercalation of soft rocks (shale) between a formation consisting of hard rock (limestone) (Fig.8).

Fig. 7 **Significance of the dip of strata for the reserve calculation**



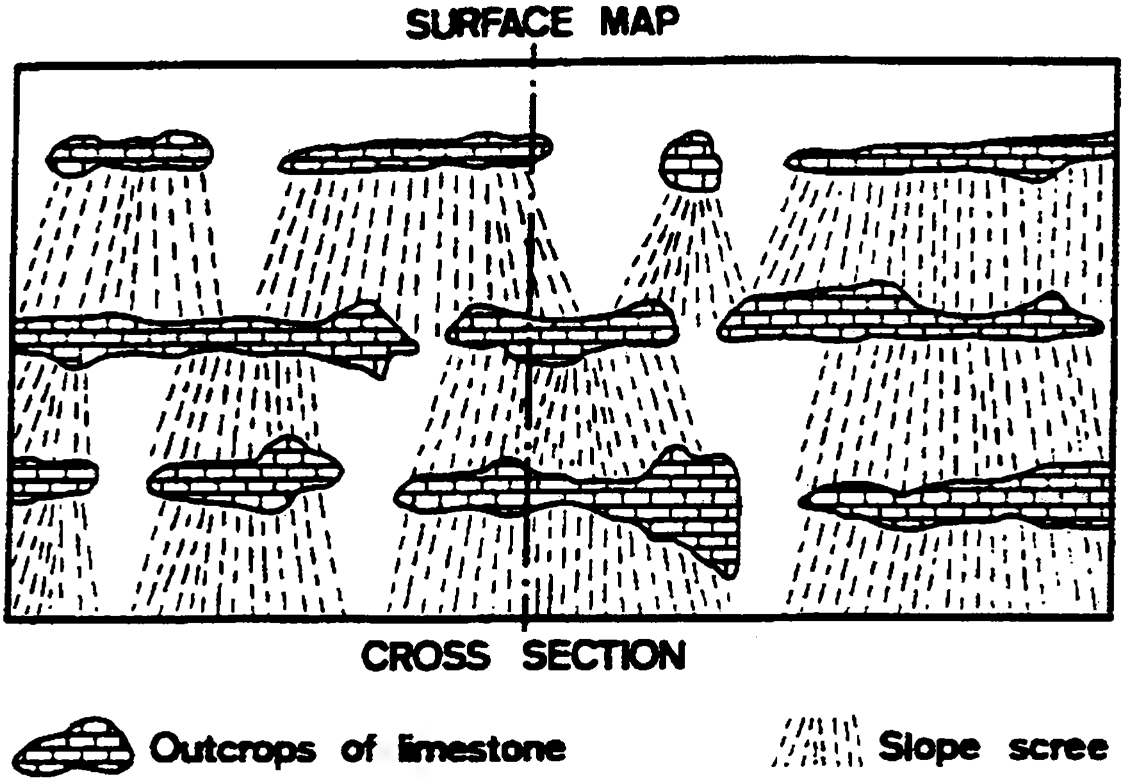
V - vertical height ≠ true thickness

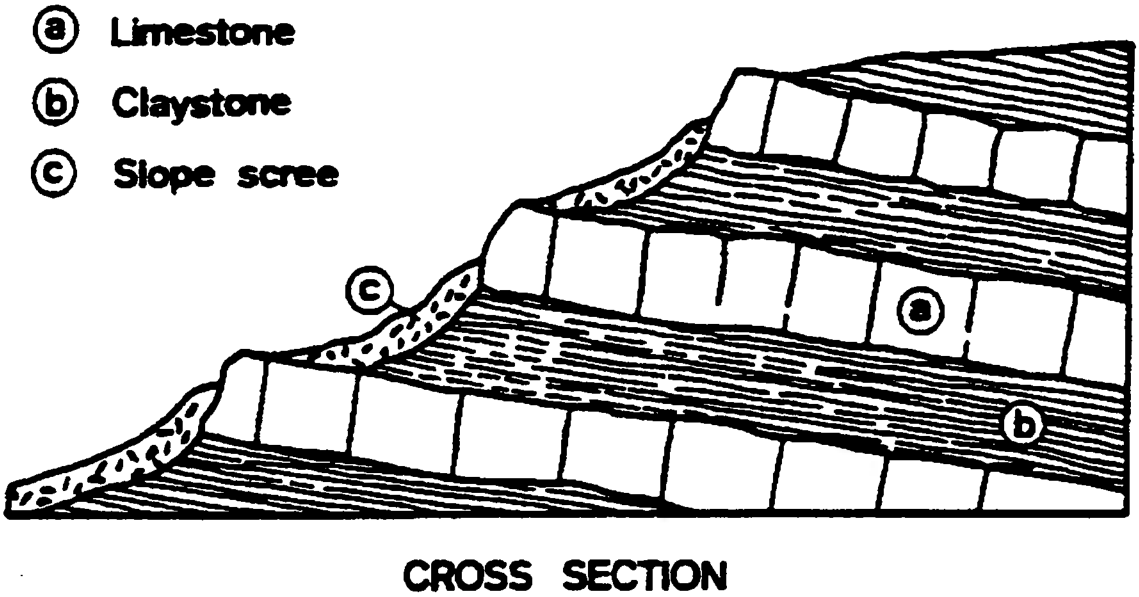
T1 = V

T1 = 2 * T2

T3 = 1.5 * T1

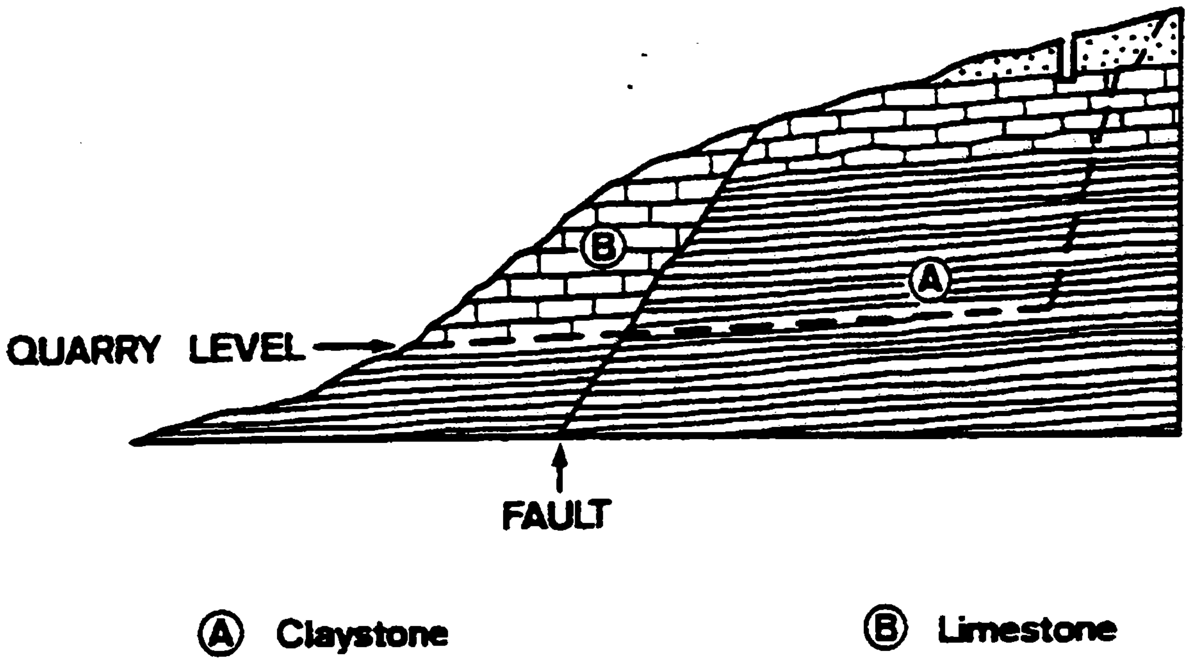
Fig. 8 **Significance of outcrop situation**





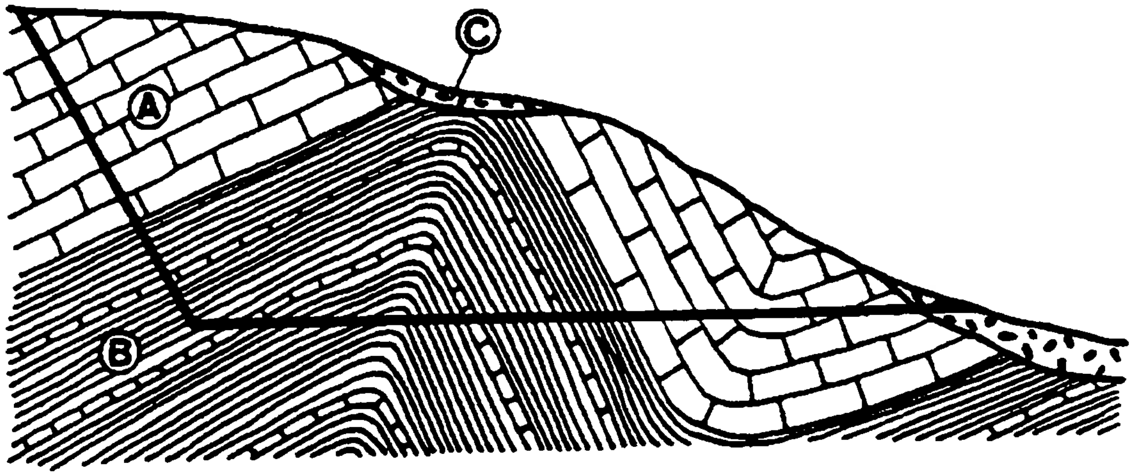
Faults may reduce the potential deposit considerably (Fig. 9).

Fig. 9 **Reduction of limestone reserves by fault tectonics**



Folding may entail incorrect reserve estimates. In this case (Fig. 10), the claystone formation could not be recognised at the surface. By measuring dip and strike, the anticline structure of this deposit would in all likelyhood have been detected.

Fig. 10 Significance of Folding



Ⓐ Limestone
Ⓑ Claystone
Ⓒ Scree

Once the geological and geochemical limits are well defined within the deposit boundaries (physical, chemical, legal, etc.) the reserve calculations can be carried out.

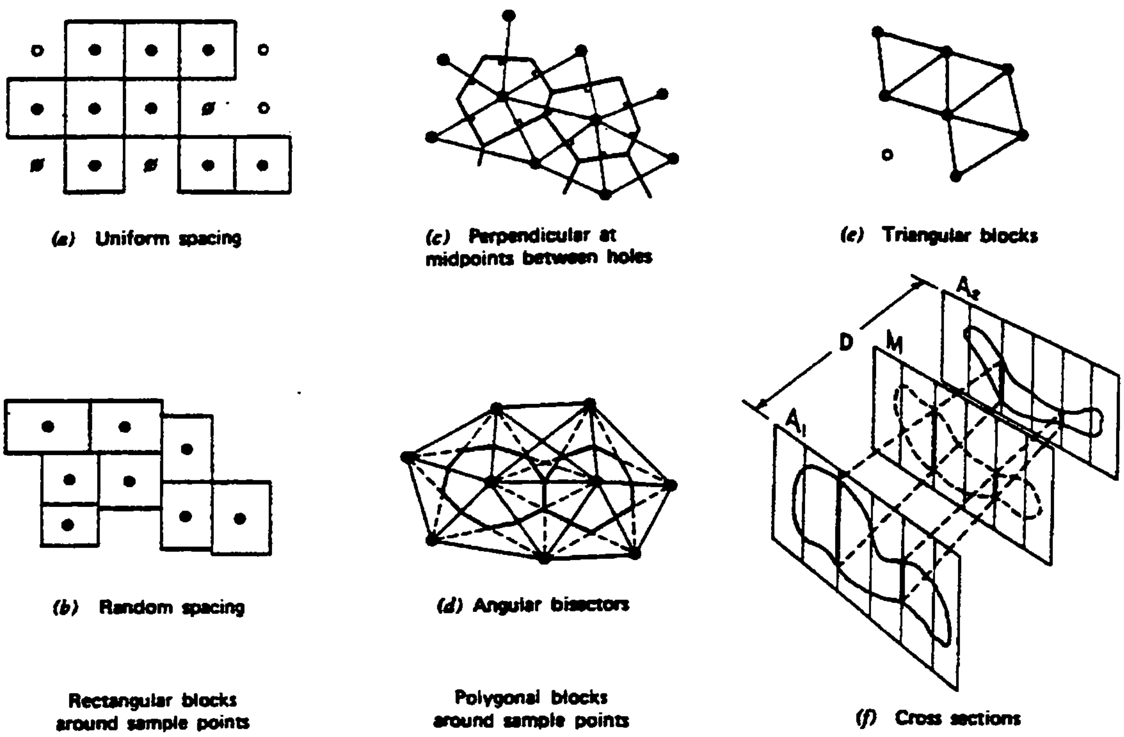
Prior to calculating the reserves the following parameters must be defined.

- Geological structure of the deposit: limit of formations
- Structures: dip and strike of stratas, folds, fault
- Overburden
- Groundwater level, natural drainage
- Qualitative limits: chemical
- Mineralogical
  - Base mining level and the final slope of the quarry
  - Physical properties
  - Economical aspect

The volume of exploitable materials can be calculated by a range of computer programs such Surfer, Surpac, ArcInfo, Vulcan, MOSS, Intergraph.

The reserve can be calculated by one of the geometric constructions shown in Fig. 11.

Fig 11 **Geometric pattern for reserves calculations**



The most suitable method to calculate the reserves is based on geological cross-sections and the distance between each parallel cross section (Fig. 11f).

$V= ((A_1 + A_2)/2) * L_{12}+ ......+ ((A_m + A_n)/2) * L_{mn}$

V = volume

A_m= surface area of the cross-section m

L_{mn}= distance between cross-sections m and n

For a deposit with horizontal stratification, the volume is quickly calculated by determining the area and multiplying it by the thickness of the useable rocks.

Calculation of the tonnage

The reserves are normally indicated in tons rather than in volume. The bulk apparent specific weight has to be determined on a few samples.

Reserves of raw material = V * r

r = density

3.3 Classification of reserves

Many attempts have been made to establish a worldwide-acceptable classification system for raw material deposits.

It is obvious that a potential deposit of cement raw materials comprises areas which are more thoroughly investigated than others, as well as zones which permit easier exploitation than others; i.e. according to the criteria:

- Degree of recognition

- Degree of exploitability

The reserves of cement raw material deposits can be divided into different classes. In the interests of presenting a useable system, we at "Holderbank" apply the following classification.

Gelogical reserves

Raw mix reserves

Mineable reserves

<u>Gelogical reserves.</u>

Geological reserves refer to those geological mineral occurrences, which are identified with satisfactory reliability of prediction (certainty of existence and geological assurance, supported with geological maps, borehole information and detailed sampling for analysis). In addition to which the identified reserves meet the preconditions set for the feasibility study (locality, accessibilty, availablity, quantitative and qualitative).

<u>Raw mix reserves.</u>

Raw mix reserves are the total reserves of all components (calcareous, siliceous and corrective), which meet the chemical criteria set for the successful operation of a particular plant.

<u>Mineable reserves.</u>

Mineable reserves are those reserves which fullfil both the aforementioned paramaters and which are practically mineable. Losses due to mining activity may include 'frozen' reserves for haulage and access roads, government and saftey restrictions as well as losses due to practical mining problems.

Table 2: US Bureau of Mines Classification System (modified)

Principle of a Resources/Reserves Classification for Raw Materials

Cumulative Prodiction (Already produced)	Identified Resources			Undiscovered Resources	
	Demonstrated				
	Measured [Proved] (Shape and contents of the resource is well established)	**Indicated** [Probable] (The degree of assurance is high enough to assume continuity between points of observation)	**Inferred** [Possible[1]] (Continuity is assumed beyond measured or indicated resources for which there is geological evidences)	Hypothetical (In known districts)	Speculative (In unknown districts)
Economic (Recovrable) Error limit % : Reliability of existence % :	Reserves (Recoverable reserves) (Extractable reserves) ± 10 >90[2]	± 20 90 - 70	Inferred Reserves <30 <70	Resources hypothetical Similar to known resources that may exist in the same region	Resources speculative Other resources
Marginally Economic [Paramarginal] (Would be economic given changes in economic or technical factors)	Marginal Reserves		Inferred Marginal Reserves		
Subeconomic [Submarginal]	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Towards top: increasing degree of profitable extraction

Towards left: increasing degree of certainity of existence, reliability of prediction and geological assurance

(white box) Reserves Base [Geological Reserves. May include part of the Inferred Reserves]

(shaded box) Inferred Reserves Base

[ ] Old terms or terms used in other classifications

( ) Short explanation of term

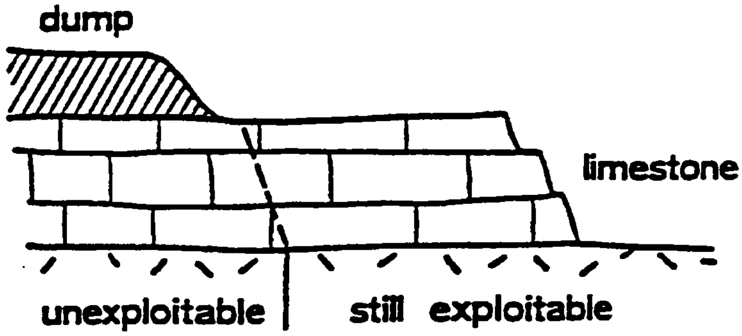
1) Some classifications divide "Possible" into "Indicated" and "Inferred"
2) Example: for an estimated reserve of 100 tons, the actual tonnage available lies between 90 and 110 tons with a probability of 90%.

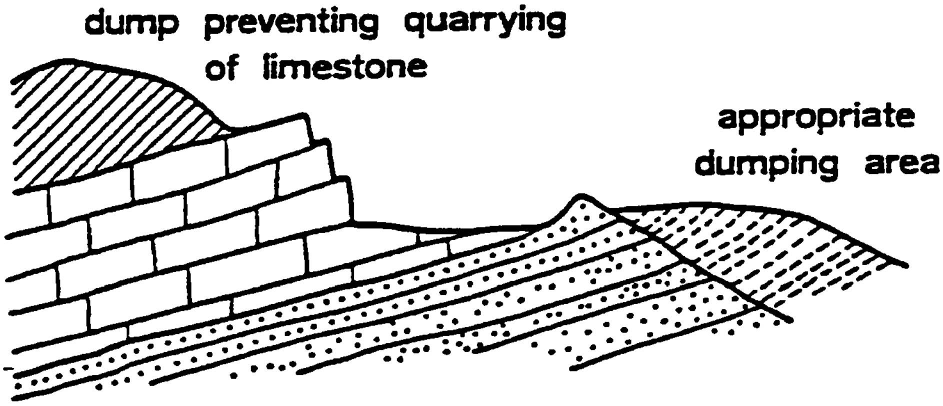
4. OVERBURDEN

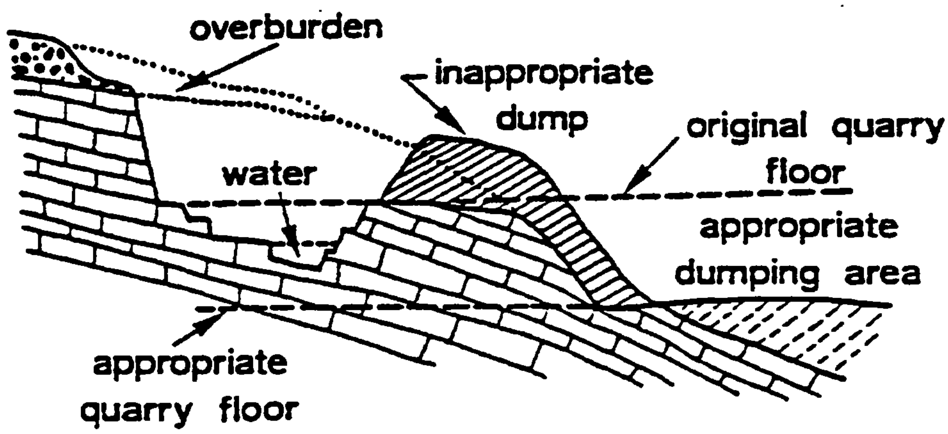
Overburden is defined as material of any nature, consolidated or unconsolidated which overlies the deposit of useful materials. Ideally, attempts should always be made to utilise the overburden material as a raw material component. Should utilisation be impossible due to chemical or physical character, the overburden is dumped in selected areas. These areas should be optimised with respect to potential rehabilitation and transportation costs. Moreover, the dumping areas should never obstruct the exploitation. Fig 12 shows few favourable and inappropriate dumping areas. Unsuitable areas of dumps may render further exploitation uneconomical and may reduce the potential reserves considerably.

In the overall investigations, the amount and the quality of the overburden must be defined accurately. An important consideration in the economics of the open pit mining is the **stripping ratio**, which is defined as the ratio of total waste removed to total suitable material mined. The **overburden ratio** is defined as the ratio of the vertical thickness of overburden to the vertical thickness of suitable material.

Fig 12: Dumping in quarry area







The volume of and the contact betwenn overburden/useful materials is determined during exploration activities eg. geological mapping, drilling, geophysics etc.

5. BULK SAMPLING TECHNOLOGICAL TESTS

At the end of the overall drilling campaign, a bulk sample is taken. This bulk sample must be representative of the deposit and comes in general from the core collection. The purpose of the bulk sample is to carry out technological tests useful to dimensioning the machinery.

The following tests are carried out:

- Chemical analyses
- Mineralogy
- Burnability
- Abrasivness
- Grindability
- Moisture content

Other tests can be carried out such as :

Brazilian test :

Uniaxial compressive strength

Bulk density

Poisson's ratio

Young's coefficient.

Crushing test:

% of fines

etc...